Towards an Analogue Neuromorphic VLSI Instrument for the Sensing of Complex Odours

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Abstract. Almost all electronic nose instruments reported today employ pattern recognition algorithms written in software and run on digital processors, e.g. micro-processors, microcontrollers or FPGAs. Conversely, in this paper we describe the analogue VLSI implementation of an electronic nose through the design of a neuromorphic olfactory chip. The modelling, design and fabrication of the chip have already been reported. Here a smart interface has been designed and characterised for thisneuromorphic chip. Thus we can demonstrate the functionality of the aVLSIneuromorphic chip, producing differing principal neuron firing patterns to real sensor response data. Further work is directed towards integrating 9 separate neuromorphic chips to create a large neuronal network to solve more complex olfactory problems.

Keywords: Neural network, Pattern recognition, Electronic nose.
PACS: 07.05.Mh

METHODS AND RESULTS

An analogue VLSI (aVLSI)neuromorphic chip has been designed and fabricated. The chip contains 3 separate neural network models, with each model having 3 receptor neurons, 27 synapses and 1 principal neuron. The aVLSI implementation of the neural network was made up by the interconnection of neurons and synapses. Each neuron in this model is made up by a leaky integrator and spike generator circuit. Both the principal and receptor neurons are made using the same configuration. The synapsescontain the weight dynamics and a synapse dynamic circuit. The synaptic circuits have individually programmable weights that are stored on chip. The aVLSI chip is fed with signals from a sensor array, with a maximum of 9 sensor inputs, and can be stacked up to contain nineaVLSI chips, increasing its processing power. This will allow up to 81 sensor inputs to be processed.The functionality of the aVLSI chip is represented in Figure 1a. An interface board for the neuromorphic chip has been designed and fabricated (Figure 1b). The size of the board is 28.5 cm × 21.0 cm. Here an odour sensor response will trigger a receptor neuron to fire/spike, consequently triggering the principal neuron, after going through a weight dynamic. The software was developed using National Instruments Labview software v8.2. The software developed for this system has three sets of connections to the interface circuitry board,

Olfaction and Electronic Nose: Proceedings of the 14th International Symposium on Olfaction and Electronic Nose
AIP Conf. Proc. 1362, 223-224 (2011); doi: 10.1063/1.3626367

which control receptor neuron input, weight programming and monitor the output from the principal neuron.

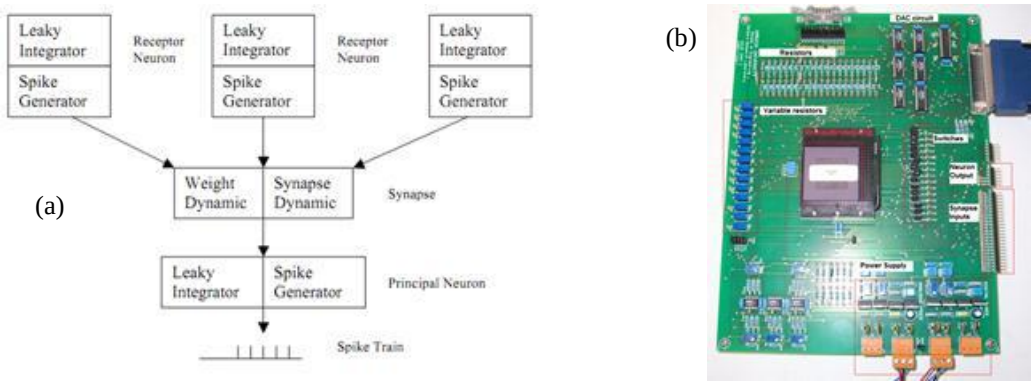

FIGURE 1. (a) Typical circuit arrangement. (b) Plot of linear discriminant functions of two bowel diseases and control samplesforelectronic nose.

The neuromorphic chip contains a series of programmable parameters that can be altered manually on the smart interface board. For example, the threshold voltage for a receptor neuron can be changed by modifying a variable resistor value. Weight programming can be performed by shifting logic 'true' through 81 D-type flip-flops while setting the weight voltage ranging from −1 to +1 V. For test purposes, weights of 0 volts were programmed into the aVLSI chip. Figure 2a shows the neuron output when the weight is set to 0 volt (no weight). With this weight theprincipal neuron will not produces any output due to the zero volt weights. Only the receptor neurons will give spikes.

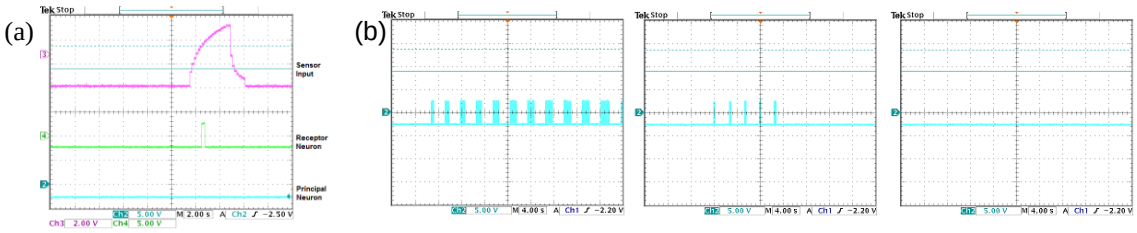

FIGURE 2.(a) Receptor and Principal neuron response when weight is 0 V. (b) Responses of 3 different neurons to 3 sets of e-nose input data. From left, the responses are for the smell of apple, coffee and tea.

Three sets of polymer array response data from tea, coffee and apple volatiles were collected and used for classification. Different neuron responseswere recorded for 3 different volatiles. Apple volatiles produced the strongest response from the sensors and resulted in the highest firing rate from the principal neuron. Figure 2b shows the three different responses from the principal neuron when provided with tea, coffee and apple data sets. From the resultsobtainedfrom these datasets, it can be seen that the principal neuron changes its firing rate based upon the response of the sensors to the different odorant samples.